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Outdoor MIMO Measurements for UTRA Applications

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ABSTRACT

MIMO techniques implemented through STBC, is a highly viable and attractive option for outdoor mobile networks. This paper presents a measurement campaign aimed at characterising the outdoor MIMO channels in the 2GHz UMTS band. Initial results comparing the channel properties and post-processing analysis for STBC schemes are also included.

I. INTRODUCTION

The use of multiple transmit and receive antennas, commonly known as MIMO (Multiple Input, Multiple Output) augmented by space-time coding, is an exciting technology emerging in the mobile/wireless communications field. It has been shown theoretically that MIMO systems can achieve spectral efficiencies of several magnitudes over the conventional SISO (Single Input, Single Output) systems [1]. The advent of space time block coding (STBC) schemes [2,3] offers reduced decoding complexity at the receiver. This has great appeal for outdoor mobile down-links where the handset design is strictly constrained with limitations on cost, power consumption and size. STBC schemes have been incorporated to the 3G UTRA-FDD standards [4], to cater for the growing demand on high bit rate services. Increasingly, STBC is seen as an effective way of bringing the advantages of MIMO technology to the outdoor mobile networks.

Within this context, accurate characterisation of outdoor MIMO channels has become essential to predict and optimise the performance enhancements of STBC schemes. This paper reports on a MIMO measurement campaign conducted in a small cell urban outdoor environment within the 2GHz UMTS band. A major part of this campaign was dedicated to tackling the problem of achieving MIMO channel measurements from a channel sounder purpose built for SIMO (Single Input, Multiple Output) measurements. Section (II) describes these hardware modifications and explains the MIMO measurement sequence adapted for the trials. In section (III), the field trial set-up, the different measurement scenarios and validation of the measurement scheme are presented. Some of the results from initial post processing are contained in section (IV). The conclusive remarks and an outline of further analysis planned with the data are given in section (V).

II. SIMO HARDWARE CUSTOMISATION FOR MIMO MEASUREMENTS

A. Hardware Customisations

The measurement system was based on a state-of-the-art wide band vector channel sounder, the Medav RUSK BRI. This channel sounder was purpose built to support SIMO measurements. In its original set-up, the sounder could transmit a multi-tone signal of up to 120MHz in bandwidth in either 2GHz or 5GHz bands. At the receiver the signal is captured sequentially by 8 individual antennas and fed to the receiver through a 8:1 multiplexer. The signals are stored in a digitized format. The speed of signal storage in the sounder enables several SIMO measurements to be completed within the channel coherence time. In order to conduct MIMO measurements, a high speed multiplexer at the transmitter to switch through multiple output ports, and digital circuitry that could maintain the synchronism between multiplexers at both ends was thus required.

It was observed that the Medav receiver follows a fixed repetitive time frame of 1024 μ s in taking measurements. Even when it is idle, readings from the 8 antenna ports are taken at this same rate for automatic gain control (AGC) purposes. This AGC burst initiated at constant intervals of 1024 μ s was selected as the timing reference for the MIMO measurements. This would provide remote synchronisation to the transmit multiplexer. Digital circuitry contained in the 'MIMO switch box' was developed to generate a 1024 μ s reference locked to the 10MHz Rhubidium clock of the Medav transmitter. Importantly this switching reference can be aligned to the AGC burst from the receiver when the latter is connected to the switch box. The reference signal is used as a master reset in the transmit antenna multiplexer circuitry of the switch box. The transmit duration for each antenna and the number of antennas can be adjusted, within this 1024 μ s time reference. Once aligned, the AGC burst can be removed after putting the switch box to its 'free running' mode. It enables the transmitter and receiver equipment to be fully isolated, a necessity for outdoor measurements.

B. MIMO measurement sequence

For these outdoor measurements, the proposed configuration was to use 4 transmit antennas and 8 receive antennas with a multi tone period of 6.4 μ s. It corresponds to 6.4 μ s maximum excess delay. As the

timing diagram in Figure 1 shows, the configuration will enable a SIMO snapshot to be taken within $6.4\mu\text{s} \times 8 \times 2 = 102.4\mu\text{s}$. The factor 2 is included because the Medav receiver leaves a blank period of time equivalent to the excess delay, when switching through the antennas. The MIMO snapshot (consisting of the instantaneous channel data of the 4Tx by 8Rx configuration) would hence require a $409.6\mu\text{s}$ duration. Within the $1024\mu\text{s}$ time grid two consecutive MIMO snapshots could be obtained which is referred to as a ‘MIMO measurement block’.

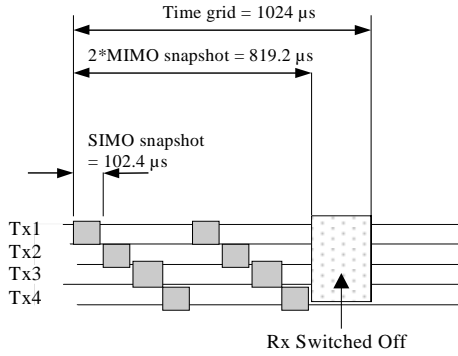


Figure 1: Timing diagram for one MIMO snapshot

Even if the maximum speed likely to be observed in a typical urban environment is assumed at 72km/h, this will still support a minimum channel coherence time of 4ms. For a realistic channel representation (as governed by the Nyquist criterion), the channel sampling should be completed within 2ms. Two instantaneous MIMO measurements are taken within 1.024ms in the above sequence. It can safely be assumed that the channel variations are negligible during this period. Thus the sequential measurements can be reasonably interpreted to resemble true MIMO parallel channels.

III. MEASUREMENT CAMPAIGN

A. System description

The field trials were carried out in Clifton, Bristol, an area with dense urban clutter. The transmitting equipment was set-up on a roof top terrace while the receiver equipment was vehicular mounted. Figure 2 depicts a functional block diagram for the measurement set-up.

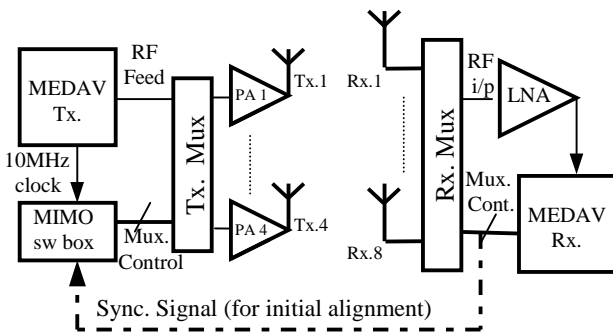
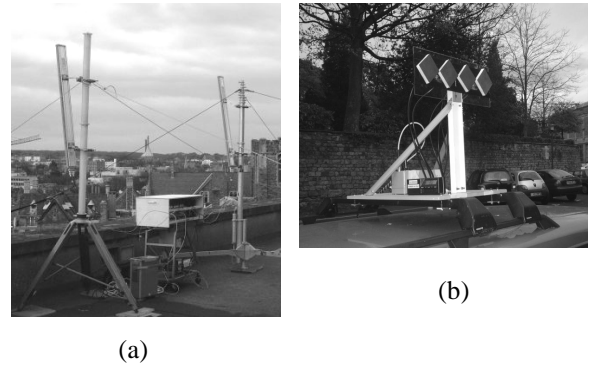


Figure 2: The measurement set-up

The multi-tone signal transmitted from the Medav was centred at 1.92GHz and covered a 20MHz bandwidth. With the output power set to 36dBm for each of the power amplifiers, the ‘spectrum re-growth’ due to non-linearities was kept within the terms of the Test and Development license. The 4 transmit ports were made up of 2 commercially available, dual polarised UMTS panel antennas. These antennas offered 17dBi gain, and cross-polar discrimination of 20dB. The antennas were mounted on the roof top, spaced 3.12m (or 20λ) apart and with 8° mechanical down tilt. At the receiving end, 4 dual polarised wide-band stacked patch antennas were used in a uniform linear array, making up the 8 receiver ports. The inter-element spacing was set at 0.5λ . Polarisation diversity was included at both ends with the intention of comparing its effectiveness in decorrelating the channels over spatial diversity. The receiving antennas provided 8dBi gain and 10dB cross-polar discrimination. The transmit and receive antenna configurations are shown below in Figure 3.



**Figure 3: (a) Transmit antennas on the rooftop
(b) Receive antennas on top the car**

The expected coverage range for this measurement set-up was around 300m. Assuming a path loss component of 3.5, it was found that the output power of 36dBm would easily achieve the required coverage.

B. Measurement scenarios

After the initial alignment of transmitter and receiver multiplexing circuitry, the receiver equipment was loaded into a car and moved around the Berkeley Square where the measurements were taken (see Figure 4). This square is surrounded by commercial and residential buildings and provided a mixture of line of sight and non-line of sight measurement points.

Two sets of measurements were taken during the trials. During the first set, the car was kept stationary at specified locations in the square. The second set consists of short drives around the square, while the measurements were carried out. For both measurement sets, a specified number of MIMO measurement blocks were taken with each block having a pre-defined number of instantaneous snapshots. As explained in

section II(B), the MIMO set-up was designed to take 8 snap shots within a MIMO measurement block, giving 2 measurements from each transmitter within the channel coherence time. However the receiver requires a much longer time to store the data to its hard disk so the repetition time for measurement blocks was 12.288ms. In each measurement 400 MIMO measurement blocks, lasting a total period of 4.9s were taken in this manner.

A map showing the transmitting and receiving locations is given in Figure 4a. Both the static measurement points and the short drive measurements are depicted here. Figure 4b and 4c show two instances of measurements being taken.

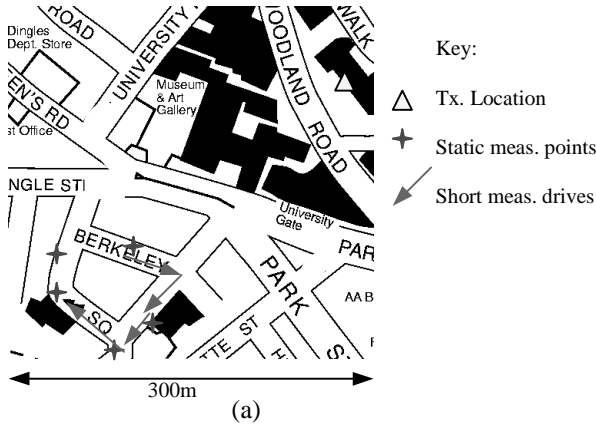


Figure 4: Field trial locations
 (a) Map of the measurement area
 (b) Static measurement point
 (c) Short measurement drive

C. Verifying synchronism between the multiplexers

In order to confirm that the initial alignment between the transmitter and receiver multiplexers was retained through out the trials, the following measurements were taken. Just after putting the MIMO switch box into its ‘free running’ mode a back to back measurement was recorded. Only the first transmit port was connected to the receiver, while the other 3 were terminated. Then after completing the field trials, the receiver was brought back to the transmit site and a similar back to back measurement was taken. The resulting impulse responses, recorded from receive port 4, are shown in Figure 5.

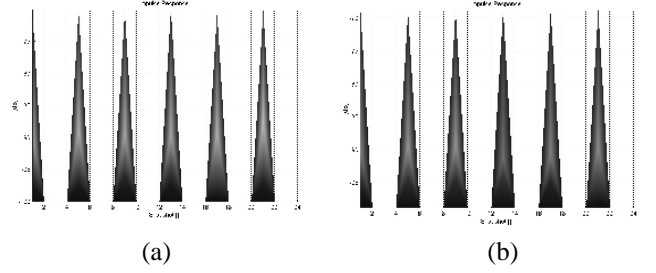


Figure 5: Snapshots from the sanity check
 (a) Before the field trials
 (b) After the field trials

The sequence of snapshots shows an active signal after 3 empty snapshots. The reason is having the transmission sequence (shown in Figure 1) repeatedly, with only the first transmit port being active. More importantly, the patterns in Figure 5a and 5b are identical. It confirms that the synchronism between the multiplexers was maintained throughout the field trials and validates the recorded channel data.

IV. INITIAL RESULTS

A. Channel correlation

A key requirement for high performance in a MIMO system is that sufficient de-correlation should exist among the constituent channels. In an outdoor system, the channel parameters vary considerably depending on the mobile locality. Hence, it is of interest to investigate the channel correlation at different measurement points.

The channel envelope correlation coefficients (at the signal peak) are presented here, for two short drive measurements. The two data files represent line of sight (LOS) and non-line of sight (NLOS) measurements. The signal bandwidth has been limited to 5MHz, to reflect a UMTS outdoor channel. The correlation coefficients are for the normalised channels connecting transmit 1 to receive 1, transmit 2 to receive 1, transmit 1 to receive 2 and transmit 2 to receive 2 ports respectively. They are given in matrices C_{LOS} and C_{NLOS} below, where the columns (and rows) follow the above transmit–receive port sequence;

$$C_{LOS} = \begin{bmatrix} 1.0000 & 0.7679 & 0.5249 & 0.4642 \\ 0.7679 & 1.0000 & 0.6429 & 0.5633 \\ 0.5249 & 0.6429 & 1.0000 & 0.8209 \\ 0.4642 & 0.5633 & 0.8209 & 1.0000 \end{bmatrix} \quad (1)$$

$$C_{NLOS} = \begin{bmatrix} 1.0000 & 0.2420 & 0.0682 & 0.0237 \\ 0.2420 & 1.0000 & 0.0721 & 0.0934 \\ 0.0682 & 0.0721 & 1.0000 & 0.3476 \\ 0.0237 & 0.0934 & 0.3476 & 1.0000 \end{bmatrix} \quad (2)$$

The NLOS channels show very good de-correlation, due to the extensive multi-path activity in these channels. But for the LOS channels the envelope correlation is much higher. The LOS channels share the same dominant signal component with little multi-path contribution to randomise the resulting channel envelope profile.

B. STBC simulations

Using the channel data, Monte Carlo simulations were conducted to investigate the performance of a UTRA-FDD down-link with STBC. The down-link DPCH (Dedicated Physical Channel) was subjected to Alamouti's Transmit diversity coding scheme [2]. The spreading factor used on the DPCH was 64 and the symbols (with no error correction coding) were QPSK modulated. The two transmit channels were corrupted with additive white Gaussian noise (AWGN). A Rake receiver with 2 active fingers (to align to the peak multi-paths from the two transmit channels) was employed at the receiver end. The simulations were carried out for LOS and NLOS radio channels mentioned in section IV (A). The bit error rate (BER) variations against the energy per bit to noise spectral density (E_b/N_0) ratio are compared in Figure 6 below.

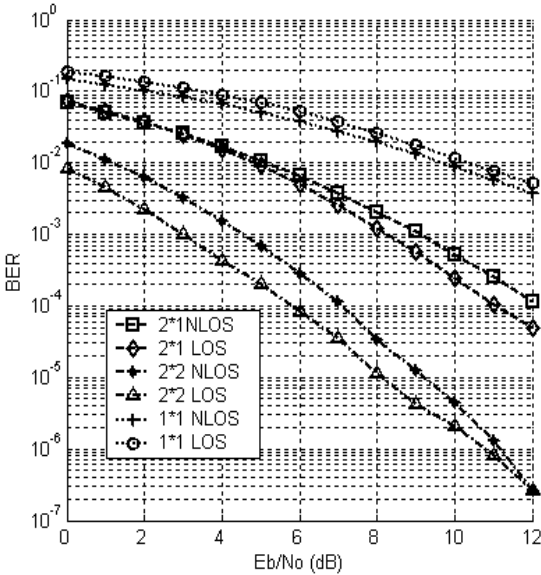


Figure 6: BER performance comparison with STBC

In both LOS and NLOS locations, the BER performance improves from the reference 1*1 cases, with the addition of extra transmit and receive ports. For the LOS channels, more of a power gain is evident in increasing the number of channels as the virtually parallel LOS curves for 2*1 and 2*2 configurations suggest. But for the NLOS channels there is some significant diversity gain as well, because the gradient of the 2*2 curve is steeper than the 2*1 curve. The higher de-correlation in the NLOS channels observed in (1) is reflected in this diversity gain.

Further STBC simulations were carried out with the NLOS channel data in a high bit rate, multi-user scenario. Eight down-link DPCH channels, each with a spreading factor of 16 (giving a nominal 240kbps data rate), were transmitted with Alamouti's diversity coding. No error correction coding was employed. Channels offering spatial and polarisation diversity at the transmitter were compared for their BER performance. The results are depicted in Figure 7 below.

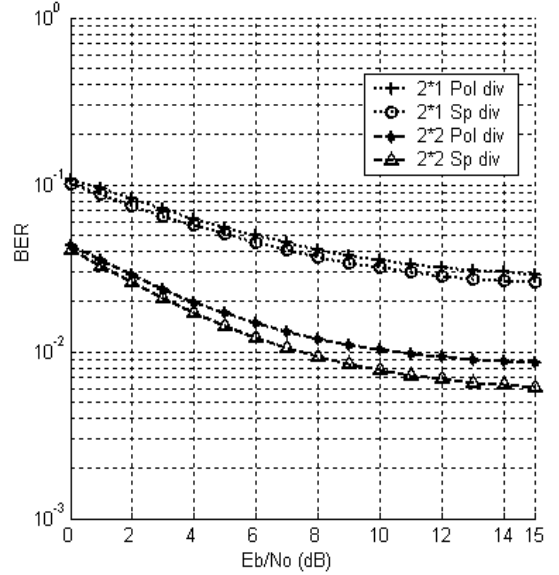


Figure 6: BER performance in multi-user, high bit rate environments

The BER curves show that the 20λ spatial separation of transmit antennas provide a slightly better performance than employing polarisation diversity. More importantly, error floors are appearing in all of the BER curves. If the recommended convolutional codes [4] were incorporated for error correction, they would shift the BER curves down by a factor around 10^{-2} , but the error floors would still remain. These error floors, product of multi-user and inter symbol interference (MUI / ISI), will be a key limiting factor in providing high bit rate multi-media services via the UTRA down-link. While the extensive multi-path activity in NLOS channels enhances diversity gain, it in turn generates more MUI / ISI in these circumstances.

V. CONCLUSIONS

This paper reports on a measurement campaign intended at characterising the outdoor MIMO channels. The customisations to the existing SIMO channel sounder and the measurement procedure is explained. The validity of the recorded data is confirmed through a sanity check. Initial results show expected variations of channel correlation for LOS and NLOS locations and their impact on BER performance. Simulations for a

high bit rate, multi-user scenario reveals the occurrence of error floors in the BER curves due to MUI / ISI.

In future, further MIMO field trial campaigns are planned with different receive antenna configurations. Also improvements in the measurement set-up are required to expand the coverage and to obtain a wider statistical sampling of the urban environment. In terms of further analysis, in-depth simulations will be carried out on multi-user systems with STBC, where it is shown that MUI/ISI will play a critical role. Conventional STBC schemes cannot negate MUI in these frequency selective outdoor channels. Hence it is planned to look into schemes which offer elimination of MUI/ISI [5,6] and investigate possible improvements to them.

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